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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

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# SILVER CEMENTATION ON COPPER, LEAD AND ZINC FROM CHLORIDE SOLUTIONS

by

D.J. MacKinnon* and J.M. Brannen**

## ABSTRACT

Silver cementation from various chloride solutions has been studied on both the disk and powder forms of copper, lead and zinc. The kinetics of silver cementation on the metal disks was characterized by an induction period which was strongly dependent on the substrate metal. The rate of silver cementation was not significantly affected by disk rotational speeds >1250 RPM or by temperatures >70°C. The induction period was eliminated and the rate of silver cementation was increased substantially when fine metal powders were used as the cementing agent. The rates of silver cementation on copper, lead and zinc powders were insensitive to temperature and solution stirring speed. The rates were rapid and both silver and copper could be removed selectively to low levels; e.g., Ag <0.5 mg/L and Cu <1 mg/L using copper powder followed by lead powder.

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# INTRODUCTION

The hydrometallurgical lead project which is currently being investigated at CANMET for treating galena concentrates includes ferric chloride leaching, solution purification and molten salt electrolysis. As indicated in the flowsheet, Figure 1, the solution purification includes a hot cementation stage for the removal and recovery of silver and copper prior to lead electrolysis.

Because chloride-based hydrometallurgical processes for the treatment of sulphide concentrates are recent innovations, little is known regarding the recovery of silver from complex chloride leach solutions. Episkoposyan and Kakovskii (1) studied the kinetics of silver cementation on a rotating iron disk from brine solutions. They observed that the cementation rate was proportional to $(rpm)^{\frac{1}{2}}$ and that the activation energy was 3 kJ/mole, indicating diffusion control. Hamdorf (2) investigated the precipitation of silver by iron from a concentrated brine solution. He observed that the precipitation of silver was a diffusion controlled, first order reaction and that the precipitation rate was insensitive to changes in chloride concentration and temperature. No studies on silver cementation on Pb, Cu or Zn from chloride media have been published.

To fill this gap in our knowledge and to provide fundamental data in support of the Hydrometallurgical Lead Process data were obtained on the cementation of silver on copper, lead and zinc; and silver and copper on lead from various chloride solutions. Those findings are noted in this preliminary report.

## EXPERIMENTAL

The following solutions, each containing 30 mg/L Ag (as AgCl) were prepared using reagent grade materials:

1) 3 M NaCl; initial pH adjusted by adding HCl; some solutions were buffered
2) 3 M NaCl + 0.3 M HCl
3) 1 M $FeCl_2$ + 0.3 M HCl
4) 3 M NaCl + 1 M $FeCl_2$ + 0.3 M HCl

Solutions containing $FeCl_2$ were pretreated with granular Pb prior to the addition of Ag to reduce the $Fe^{3+}$ concentration to very low levels.

The cementation reactions were carried out in a vessel containing 300 mL of the desired solution and fitted with a cover designed to hold and position a thermometer, pH electrodes and stirring shaft; the cover also contained a sampling port from which solution was withdrawn at timed intervals for analysis by atomic absorption spectrophotometry. The reaction vessel was placed in a thermostated water bath to maintain the temperature, generally at 70°C.

Three-quarter inch diameter disks of copper, lead and zinc were pressure fitted into a specially designed Plexiglas disk holder, Figure 2(a), such that the circular face of the metal was exposed. The tapered end of the disk holder was drilled and threaded to accommodate a ¼ in. diameter plexiglass stirring shaft. Prior to each test, the exposed face of the metal disks was polished using 400 grit paper followed by 600 grit paper and finally by 0.2 μm alumina.

In the tests involving silver cementation on granular or powdered metals, a known weight of the metal was added to the solution to initiate the reaction. A specially designed Plexiglas stirrer, Figure 2(b), was

used to provide intimate mixing of the metal powder and solution. The stirrer, 2.0 inches in diameter and ½-inch thick, was connected to a ½-inch diameter Plexiglas shaft. Four equally spaced 3/8-inch holes were drilled at 60° angles to the central shaft around the flat surface of the disk and ½-inch from its edge. Solution samples were withdrawn through a glass frit to ensure that no metallic particles were entrained.

## RESULTS AND DISCUSSION

### 1. NaCl Solution - Various pH's

#### a) Metal Disks

Initial experiments were done using a solution consisting of 30 mg/L Ag in 3.0 M NaCl at pH 6.2. These experiments indicated that the rate of silver cementation was not significantly enhanced either by increasing the temperature above 70°C or by varying the rotational velocity of the disk above 1250 RPM. The solution pH increased from 6.2 to 8.0 during the 60-90 minute experiments.

A typical result is shown in Figure 3 as a plot of Ag cemented (mg/L) vs time (min). The data presented in Figure 3 were obtained using a copper disk rotated at 1250 RPM in a 3.0 M NaCl solution at pH 6.2 and containing 30 mg/L Ag at 70°C. These data were obtained for two types of surface pretreatment; viz., 1) a final polish with 600 grit paper and 2) a final polish with 0.2 μm $Al_2O_3$ paste. As indicated in Figure 3, there was an induction period of 15-20 minutes prior to the cementation of Ag onto the copper disk. The surface pretreatment of the disk had only a slight effect on the length of the induction period or on the rate of Ag cementation. The rate of Ag cementation on Cu, Pb and Zn disks is indicated in Table 1 as a function of surface pretreatment.

The effect of solution pH on the rate of Ag cementation on Cu, Pb and Zn disks was studied at 70°C and 1250 RPM. The results indicate that the optimum rate of Ag cementation occurs when the solution is buffered at pH 4.0. Figure 4 compares the results obtained using a Cu disk polished with 0.2 μm $Al_2O_3$ paste in a solution buffered at pH 4.0 and in a solution at initial pH 6.2. The results from the buffered solution indicate an increase in the cementation rate and a slight reduction in the induction period. The data obtained for Cu, Pb and Zn disks are summarized in Table 2; as indicated, a significant increase in the rate of Ag cementation occurs in the buffered solutions, particularly for the Pb and Zn disks.

The cementation of Ag on Cu, Pb and Zn disks from a 3.0 M NaCl - 30 mg/L Ag solution buffered at pH 4.0 is shown in Figure 5 in the form of a Ag cemented (mg/L) vs time (min) plot. The initial rate of Ag cementation on the Cu disk is slow. After about 20 minutes the rate increases linearly with time and most of the Ag is cemented from solution in 90 minutes. Ag cementation on Pb and Zn disks is characterized by a slow initial rate which abruptly increases after 10 minutes; after 40 minutes the rate gradually decreases and approximately the same amount of Ag is cemented from solution in 90 minutes as was the case for the Cu disk.

The type of metal surface and the solution pH both had an effect on the morphology of the cemented silver. Figure 6 shows a series of SEM photomicrographs depicting the morphology of Ag cemented on disks of Cu, Pb and Zn, both for a solution buffered at pH 4.0 and for one of initial pH 6.2. Silver cemented on a Cu disk (solution pH 6.2), Figure 6(a), was characterized by leaf-like dendrites which grew outwards into the solution. In the buffered solution, fewer leaf-like dendrites and a more even deposit, mainly consisting of non-uniform, isolated particles, were obtained, Figure 6(b).

The Ag deposit on the Pb disk (solution pH 6.2), Figure 6(c), consisted of long, needle-like growths which extended outward into the solution; the Ag deposit obtained from the buffered solution, Figure 6(d), consisted of non-uniform particles which resided in the lead surface recesses. Silver cemented on the Zn disk (solution pH 6.2), Figure 6(e), consisted of fine needle-like growths interspersed with clusters of non-uniform particles; in the buffer solution the Ag deposit, Figure 6(f), was composed of larger, flat, irregularly shaped particles which resulted in a more uniform surface coverage.

b) Metal Powders

The cementation of Ag on Cu, Pb and Zn powders was studied in 3.0 M NaCl solution buffered at pH 4.0, 70°C, and stirred at 1250 RPM. The results obtained using 0.1 g of Cu, Pb and Zn powders are shown in Figure 7 as a plot of Ag cemented (mg/L) vs time (min). These results indicate a considerable reduction in the induction period and substantial increase in the cementation rate compared to the metal disks. The initial rate of Ag cementation is faster on the Pb and Zn powders than on the Cu powder, as was the case for the metal disks, Table 3. In the case of the metal disks, all of which have the same apparent surface area, 1.27 $cm^2$, the difference in initial rate may be related to the large differencies in the free energy for the cementation of Ag on Cu (-2 kcal/mole) as compared to Pb (-23 kcal/mole) and Zn (-45 kcal/mole). However, because the free energy for Ag cementation on Zn is about twice that for Pb, one might expect the initial rate of Ag cementation on Zn to be faster than that on Pb. The similar rates may be rationalized in terms of real surface area. Given that Pb is a much softer metal, the surface polishing treatment would tend to

produce a "rougher" Pb surface compared to the Zn surface. This seems to be the case as indicated by the SEM photomicrographs in Figure 6(d) and 6(f). Similar arguments may also apply to the metal powders as the SEM photomicrographs (Figure 8) indicate that the surface area of the Pb powder > Zn powder > Cu powder. A comparison of the rates of Ag cementation on the metal powders and disks is given in Table 3.

Figure 8 shows a series of SEM photomicrographs depicting the morphology of cemented Ag on the various metal powders; very similar deposit structures were obtained in all cases.

The results obtained for Ag cementation on fine Pb powder and on various amounts of granular Pb are shown in Figure 9. The results indicate a significant surface area effect since the initial rate of Ag cementation is much faster (approximately 23 times) on 0.1 g of fine Pb powder as compared to 0.1 g of granular Pb. Increasing the amount of granular Pb results in a proportionate increase in the initial cementation rate.

## 2. 3 M NaCl + 0.3 M HCl Solution

### a) Effect of Atmosphere

The cementation of Ag on Cu and Pb was also studied using a 3.0 M NaCl + 0.3 M HCl solution containing 30 mg/L Ag. It was observed that when the reaction was carried out under an inert $N_2$ atmosphere, the pH of the solution did not change. The effect of the $N_2$ atmosphere on Ag cementation on Cu powder is shown in Figure 10. These results were obtained for 0.5 g Cu powder, 70°C and for a solution stirring rate of 1250 RPM, with and without an $N_2$ atmosphere. The data indicate that after about 30 minutes, the cemented Ag begins to redissolve for the case where $N_2$ was not used; after 90 minutes the Ag has completely redissolved together with most of the Cu powder.

b) Effect of $CuCl_2$

The results obtained for Ag cementation on 0.5 g Pb powder from solutions containing 0 and 250 mg/L $Cu^{2+}$ (as $CuCl_2$) are shown in Figure 11. The rate of Ag cementation on Pb powder is very rapid, the reaction being completed in about 10 minutes. In the presence of $CuCl_2$, the rate is almost twice as fast; i.e., 15 mg/min as compared to 8.8 mg/min in the absence of $Cu^{2+}$.

Figure 12 shows a comparison of Ag cementation on 0.5 g of Pb powder and on a Pb disk from a solution containing 250 mg/L Cu (as $CuCl_2$). As indicated, the rate of Ag cementation on the Pb disk is much slower than that on the Pb powder.

c) Quantity of Metal Powder

Silver cementation on Cu and Pb powders was also studied as a function of the quantity of powder added to the solution. The rate of Ag cementation was obtained for various amounts of powders up to 0.5 g. The results are shown in Figure 13 as a plot of rate (mg/L/min) vs weight of metal (g). The rate of Ag cementation on Pb powder levels off at 0.3 g Pb powder, whereas, that on Cu powder shows a linear increase up to 0.5 g Cu. The initial slope of the curve for Pb powder is about 45 mg/L/min/g Pb as compared to 5 mg/L/min/g Cu for the Cu powder.

The percentage Ag cemented and the excess metal consumed as a function of the amount of Cu and Pb powder added to the solution are given in Tables 4 and 5, respectively. The data in Table 4 indicate that the total Ag cemented from solution increased with increasing amounts of Cu powder. Although all tests were run for 60 minutes, that using 0.5 g Cu powder was completed in 30 minutes. The excess Cu consumed was approximately

twice the stoichiometric requirement and this value appeared to be independent of the amount of Ag precipitated.

Similar data are shown for Ag cementation as a function of the amount of Pb powder in Table 5. Although the rate of Ag cementation increased significantly by increasing the amount of Pb powder added to the solution (see Figure 13), the total amount of Ag cemented was about the same. However, the time for virtually complete reaction decreased markedly with the addition of larger quantities of Pb powder; e.g., at 0.2 g Pb, all of the Ag was cemented in 50 minutes whereas at 0.5 g Pb, only 10 minutes were required to complete the reaction. Table 5 also indicates that considerable excess Pb was consumed during the reaction and that the amount increased with increasing quantities of Pb powder. This occurred because Pb continued to dissolve after the Ag had been cemented; different behaviour was observed for copper powders (Table 4), presumably because of the more inert nature of copper.

d) Ag and Cu Cementation on Pb Powder

Tests were also done in which both Ag and Cu were cemented together on various amounts of Pb powder. The results, summarized in Table 6, indicate that 99% of the Ag and Cu was removed from solution. Although these tests were run for 60 minutes, the reactions were very rapid; e.g., for 1.0 and 2.0 g Pb powder, most of the Ag and Cu were cemented from solution in 7 and 5 minutes, respectively. Also in this case, the Pb powder did not continue to dissolve after the Cu and Ag had been cemented, resulting in an excess Pb consumption of only 1.5 times the stoichiometric requirement.

e) Two-Stage Cementation

Silver and copper were also cemented from solution successively using Cu and Pb powders. In this case, most of the Ag was cemented on the Cu powder followed by Cu and residual Ag cementation on Pb powder. The results, summarized in Table 7, indicate that the Ag in solution was reduced to <0.03 mg/L whereas Cu was reduced to 0.8 mg/L. The plots in Figure 14 show that the initial rate of Ag cementation on 0.5 g of Cu powder was about 2 mg/L/min and that for Cu cementation on 1 g of Pb powder was 240 mg/L/min.

3. 1 M $FeCl_2$ + 0.3 M HCl

Silver cementation on Cu and Pb powders was also studied using 1 M $FeCl_2$ + 0.3 M HCl solutions at 70°C and a stirring rate of 1250 RPM. Initial tests indicated that Ag could not be cemented from this solution because of the presence of trace amounts of ferric ion present in the ferrous media. Thus, in preparing the cementation solution, it was necessary to pre-reduce the ferrous solution using either Fe or Pb metal before adding the required concentration of AgCl; it was also necessary to maintain the solution under an $N_2$ atmosphere both during the reduction and the subsequent cementation reaction.

Both Fe powder and granular Pb were evaluated as reductants for ferric ion. The results shown in Figure 15 indicate that the solution pretreated with Fe powder was not completely $Fe^{3+}$-free, since the cemented Ag began to redissolve after about 5 minutes; almost complete Ag removal was achieved for the solution pretreated with granular Pb.

The rates of Ag cementation (from a solution pretreated with granular Pb) on 0.5 g of Cu and Pb powders are compared in Figure 16. The initial rate of Ag cementation on Pb powder, 5.6 mg/L/min, was about 10 times faster than that on Cu powder, 0.5 mg/L/min, under similar conditions Also, virtually complete Ag removal was achieved using Pb powders, whereas only about 80% Ag precipitation was possible using Cu powder during the 80 minute tests.

Silver was also cemented on both Pb and Cu powders using a solution composed of 3.0 M NaCl + 1.0 M $FeCl_2$ + 0.3 M HCl containing 30 mg/L Ag (as AgCl). The solution was pretreated with granular Pb under an $N_2$ atmosphere. As indicated in Figure 17, the initial Ag cementation rate on 0.5 g Pb powder (10 mg/L/min) was about 10 times faster than the initial rate on 0.5 g Cu powder (1.1 mg/L/min); after 50 minutes the Ag was completely removed by the Pb powder but only about 79% precipitated by the Cu powder.

## CONCLUSIONS

The cementation of silver on rotating disks of copper, lead and zinc from NaCl solutions was characterized by an induction period of 15-20 minutes. The induction period was only slightly affected by the disk surface pretreatment and by the solution pH. Optimum rates of Ag cementation on the metal disks were obtained when the solution was buffered at pH 4.0. The induction period was eliminated when fine metal powders were used instead of the metal disks.

A nitrogen atmosphere was required to prevent re-solution of the cemented silver when a NaCl-0.3 HCl solution was used. The rate of silver cementation on lead powder was enhanced when the solution also

contained 250 mg/L $CuCl_2$. The rate of silver cementation on lead powder was maximized when 0.3 g of the powder was added to the solution.

To cement silver from $FeCl_2$-0.3 M HCl solutions it was necessary to pretreat the solution with granular Pb to reduce the ferric ion concentration to low levels. The rates of silver cementation on copper or lead powder were insensitive to temperature and solution stirring speed. The rates were rapid and both silver and copper could be removed selectively to low levels; e.g., Ag <0.5 mg/L and Cu <1 mg/L using copper powder followed by lead powder.

## ACKNOWLEDGEMENTS

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## REFERENCES

1 - Episkoposyan, M.L. and Kakovskii, I.A. "An Examination of Copper and Silver Cementation Kinetics with Metallic Iron from Chloride Solutions"; Tsvt Met 6:16; 1965.

2 - Hamdorf, C.J. "Precipitation of Lead and Silver from Brine Solutions by Metallic Iron"; Proc Aust Inst Min and Met 199:19; 1961.

Table 1 - Effect of Disk Surface Pretreatment on the Rate of Silver Cementation from NaCl Solution

| Disk Metal | Cementation Rate (L/min) | |
|---|---|---|
| | 600 grit | 0.2 μ $Al_2O_3$ |
| Cu | 0.29 | 0.27 |
| Pb | 0.33 | 0.35 |
| Zn | 0.33 | 0.26 |

3.0 M NaCl; 30 mg/L Ag; Initial pH 6.2;
70°C; 1250 RPM; Disk area = 1.27 $cm^2$.

Table 2 - Effect of Solution pH on the Rate of Silver Cementation from NaCl Solution

| Disk Metal | Cementation Rate (mg/L/min) | |
|---|---|---|
| | pH = 6.2 | Buffered pH = 4.0 |
| Cu | 0.27 | 0.34 |
| Pb | 0.35 | 0.56 |
| Zn | 0.26 | 0.56 |

3.0 M NaCl; 30 mg/L Ag; 0.2 μm $Al_2O_3$ polish; 70°C; 1250 RPM; Disk Area = 1.27 $cm^2$.

Table 3 - Comparison of Silver Cementation Rates on Cu, Pb and Zn Disks and Powders

| Metal | Cementation Rate | |
|---|---|---|
| | Disk | 0.1 g powder |
| | 0.2 μm $Al_2O_3$ | |
| Cu | 0.34 | 1.0 |
| Pb | 0.56 | 3.0 |
| Zn | 0.56 | 3.0 |

3.0 M NaCl; 30 mg/L Ag; Buffered pH = 4.0

70°C; 1250 RPM; Disk area = 1.27 $cm^2$

Table 4 - Ag Cementation on Cu Powder

| Wt. Cu | Ag | | Cu | | % Ag | Excess Cu |
|---|---|---|---|---|---|---|
| (g) | Init. | Fin. | Init. | Fin. | Cemented | Dissolved |
| 0.10 | 34.2 | 7.0 | - | 24 | 80.0 | 1.7X Stoic. |
| 0.25 | 27.3 | 0.9 | - | 34 | 96.7 | 2.0X Stoic. |
| 0.50 | 30 | 0.4 | - | 31 | 98.7 | 1.6X Stoic. |

Table 5 - Ag Cementation on Pb Powder

| Wt. Pb | Solution Analyses (mg/L) Ag | | Pb | | % Ag | Excess Pb |
|---|---|---|---|---|---|---|
| (g) | Init. | Fin. | Init. | Fin. | Cemented | Dissolved |
| 0.10 | 34.8 | 0.3 | - | 65 | 99.1 | 2.3X Stoic. |
| 0.20 | 33.9 | 0.4 | - | 190 | 98.8 | 5.5X Stoic. |
| 0.35 | 31.8 | 0.4 | - | 280 | 98.7 | 8.9X Stoic. |
| 0.50 | 32.4 | 0.5 | - | 290 | 98.5 | 10.2X Stoic. |

Table 6 - Silver and Copper Cementation on Lead Powder

| Wt. Pb | Solution Analyses (mg/L) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ag | | Cu | | Pb | | Metal Cemented(%) | | Excess Pb |
| | Init. | Fin. | Init. | Fin. | Init. | Fin. | Ag | Cu | Dissolved |
| 1.0 | 28.8 | 0.6 | 256 | 3.0 | - | 1250 | 97.9 | 98.1 | 1.5X Stoic. |
| 1.5 | 30.0 | 0.6 | 268 | 3.0 | - | 1980 | 98.8 | 98.9 | 1.3X Stoic. |
| 2.0 | 34.2 | 0.4 | 245 | 3.0 | - | 1511 | 98.8 | 99.2 | 1.4X Stoic. |

Table 7 - Two-Stage Cementation; Ag/Cu; Cu/Pb

| Metal Added | Solution Analysis (mg/L) | | | | Metal Cemented (%) | |
|---|---|---|---|---|---|---|
| | Ag | | Cu | | | |
| | Init. | Fin. | Init. | Fin. | Ag | Cu |
| 0.5 g Cu | 28.8 | 0.6 | 250 | 410 | 97.9 | - |
| 1.0 g Pb | 0.6 | <0.03 | 410 | 0.8 | 99.9 | 99.8 |

## CAPTIONS TO FIGURES

Fig. 1 - Flowsheet of a hydrometallurgical lead process for treating galena concentrate.

Fig. 2 - Schematic drawings of (a) metal disk holder and (b) circulating disk for metal powders.

Fig. 3 - Plots of Ag cemented vs time showing the effect of surface pretreatment on Ag cementation on a Cu disk rotated at 1250 RPM in 3.0 M NaCl solution; pH 6.2; 70°C.

Fig. 4 - Plots of Ag cemented vs time showing the effect of pH on Ag cementation on a Cu disk rotated at 1250 RPM in 3.0 M NaCl solution; 70°C.

Fig. 5 - Plots of Ag cemented vs time comparing Ag cementation on various metal disks rotated at 1250 RPM from 3.0 M NaCl solution; pH 4.0; 70°C.

Fig. 6 - SEM photomicrographs showing the effect of pH on the morphology of Ag cemented on Cu, Pb and Zn disks rotated at 1250 RPM in 3.0 M NaCl solution; 70°C.

Fig. 7 - Plots of Ag cemented vs time comparing Ag cementation on various metal powders from 3.0 M NaCl solution stirred at 1250 RPM; pH 4.0; 70°C.

Fig. 8 - SEM photomicrographs showing the morphology of Ag cemented on metal powders from 3.0 M NaCl solution stirred at 1250 RPM; pH 4.0; 70°C.

Fig. 9 - Plots of Ag cemented vs time comparing Ag cementation on Pb powder and granular Pb from 3.0 M NaCl solution stirred at 1250 RPM; pH 4.0; 70°C.

Fig. 10 - Plots of Ag cemented vs time showing the effect of $N_2$ atmosphere on Ag cementation on Cu powder from 3.0 M NaCl + 0.3 M HCl solution stirred at 250 RPM; 70°C.

Fig. 11 - Plots of Ag cemented vs time showing the effect of $CuCl_2$ on Ag cementation on Pb powder from 3.0 M NaCl + 0.3 M HCl solution stirred at 1250 RPM; 70°C.

Fig. 12 - Plots of Ag cemented vs time comparing Ag cementation on Pb powder and Pb disks from 3.0 M NaCl + 0.3 M HCl solution; 1250 RPM; 70°C.

Fig. 13 - Plots of rate of Ag cementation vs weight of metal powder for Ag cementation on Pb and Cu powders from 3.0 M NaCl + 0.3 M HCl solution stirred at 1250 RPM; 70°C.

Fig. 14 - Plots of Ag and Cu cementation vs time on Cu and Pb powder, respectively, from 3.0 M NaCl + 0.3 M HCl solution stirred at 1250 RPM; 70°C.

Fig. 15 - Plots of Ag cemented vs time showing the effect of solution pretreatment on Ag cementation on Pb powder from 1.0 M $FeCl_2$ + 0.3 M HCl solution stirred at 1250 RPM; 70°C.

Fig. 16 - Plots of Ag cemented vs time comparing Ag cementation on Pb and Cu powders from 1.0 M $FeCl_2$ + 0.3 M HCl solution stirred at 1250 RPM; 70°C.

Fig. 17 - Plots of Ag cemented vs time comparing Ag cementation on Cu and Pb powders from 3.0 M NaCl + 1.0 M $FeCl_2$ + 0.3 M HCl solution stirred at 1250 RPM; 70°C.

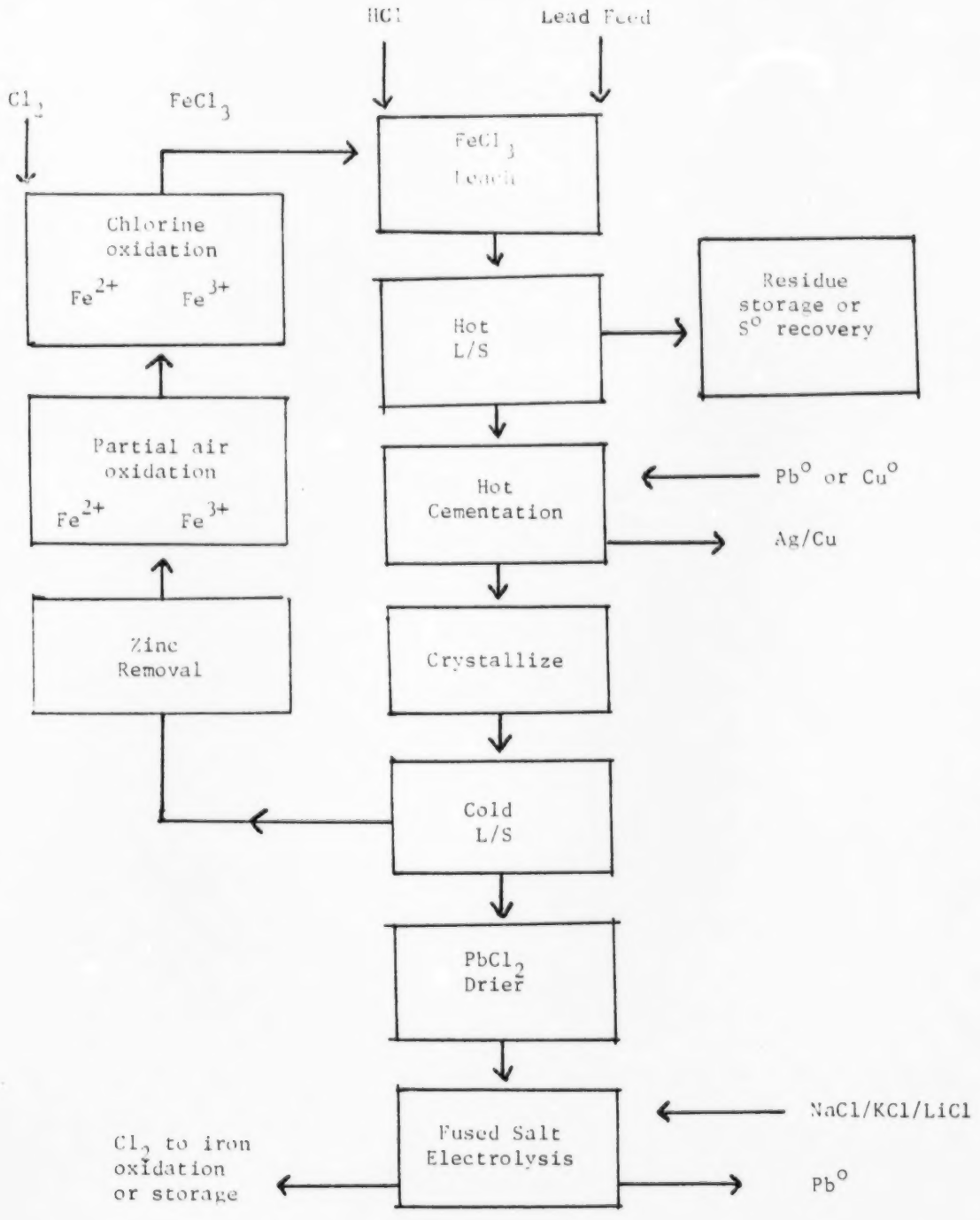
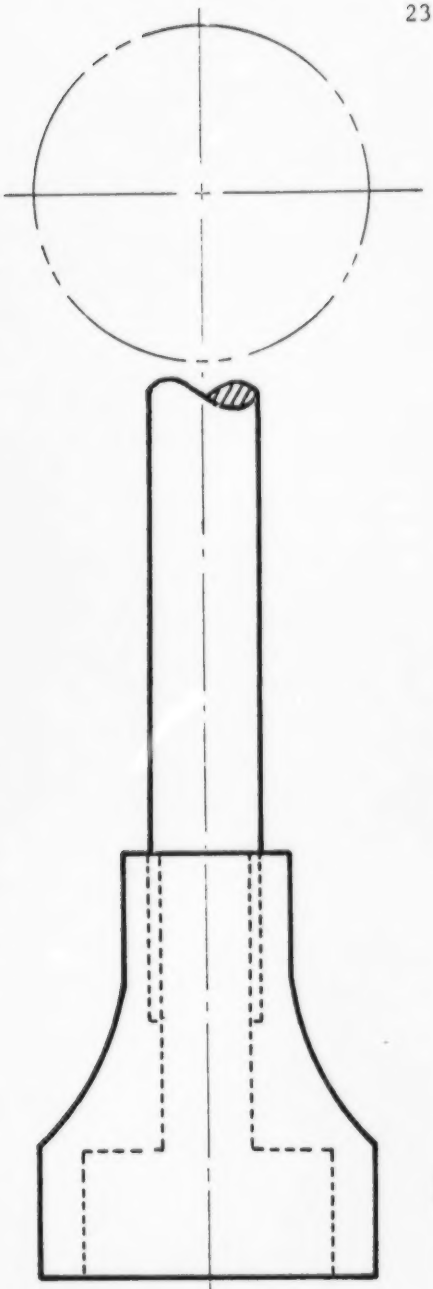
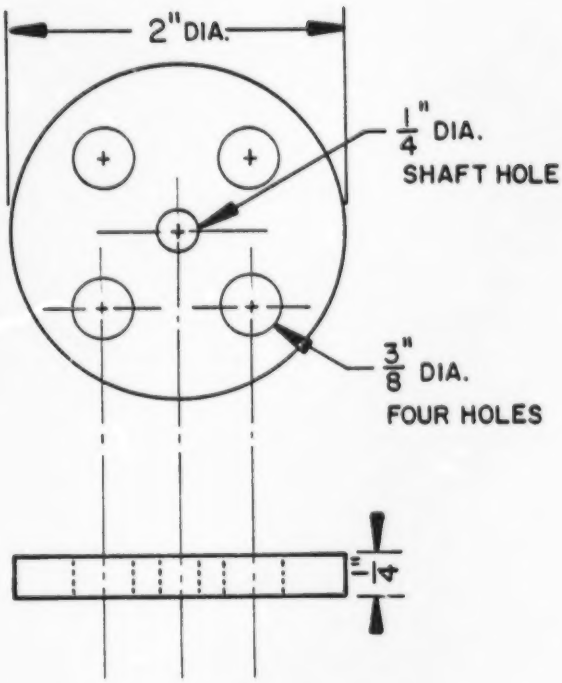



Figure 1 - Flowsheet of a hydrometallurgical lead process for treating galena concentrates.



PLEXIGLAS HOLDER
FOR METAL DISKS
A




CIRCULATING DISK
FOR METAL POWDERS
B

JDM

FIG. 2

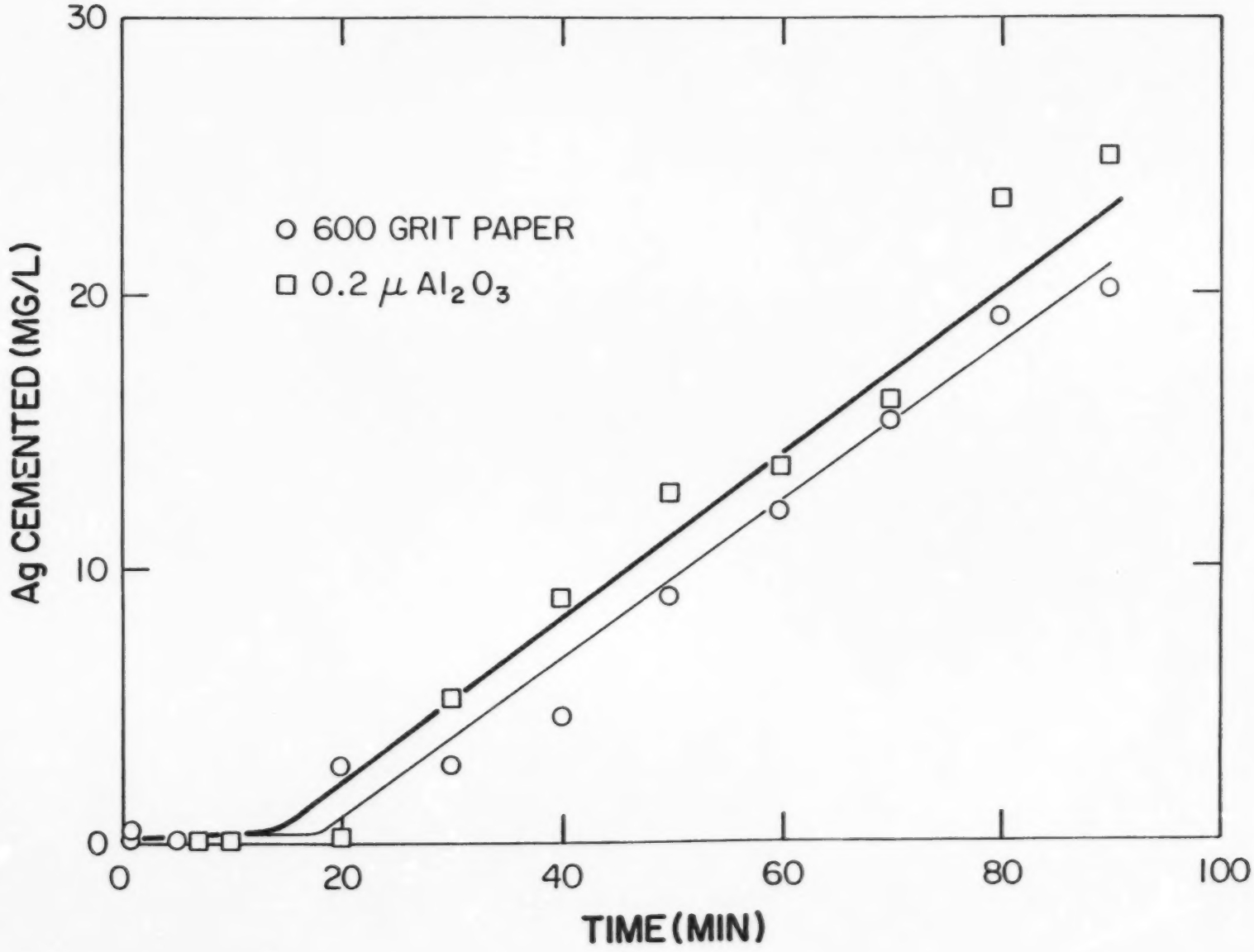

30
20
10
0
0
20
40
60
80
100
Ag CEMENTED (MG/L)
TIME (MIN)
○ 600 GRIT PAPER
□ 0.2 μ Al2O3

FIG. 3

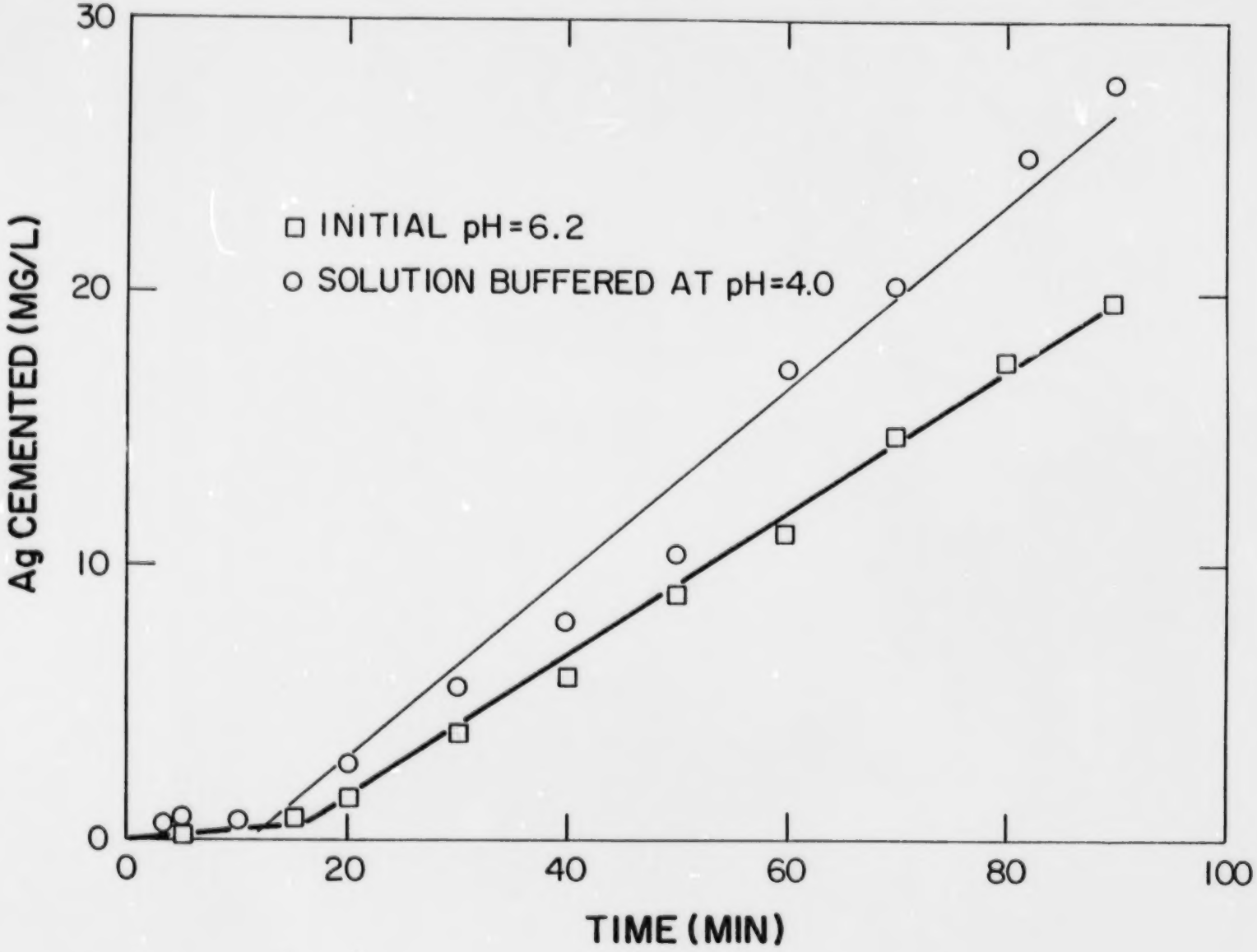

30
20
10
0
0
20
40
60
80
100
Ag CEMENTED (MG/L)
TIME (MIN)
□ INITIAL pH=6.2
○ SOLUTION BUFFERED AT pH=4.0

FIG. 4

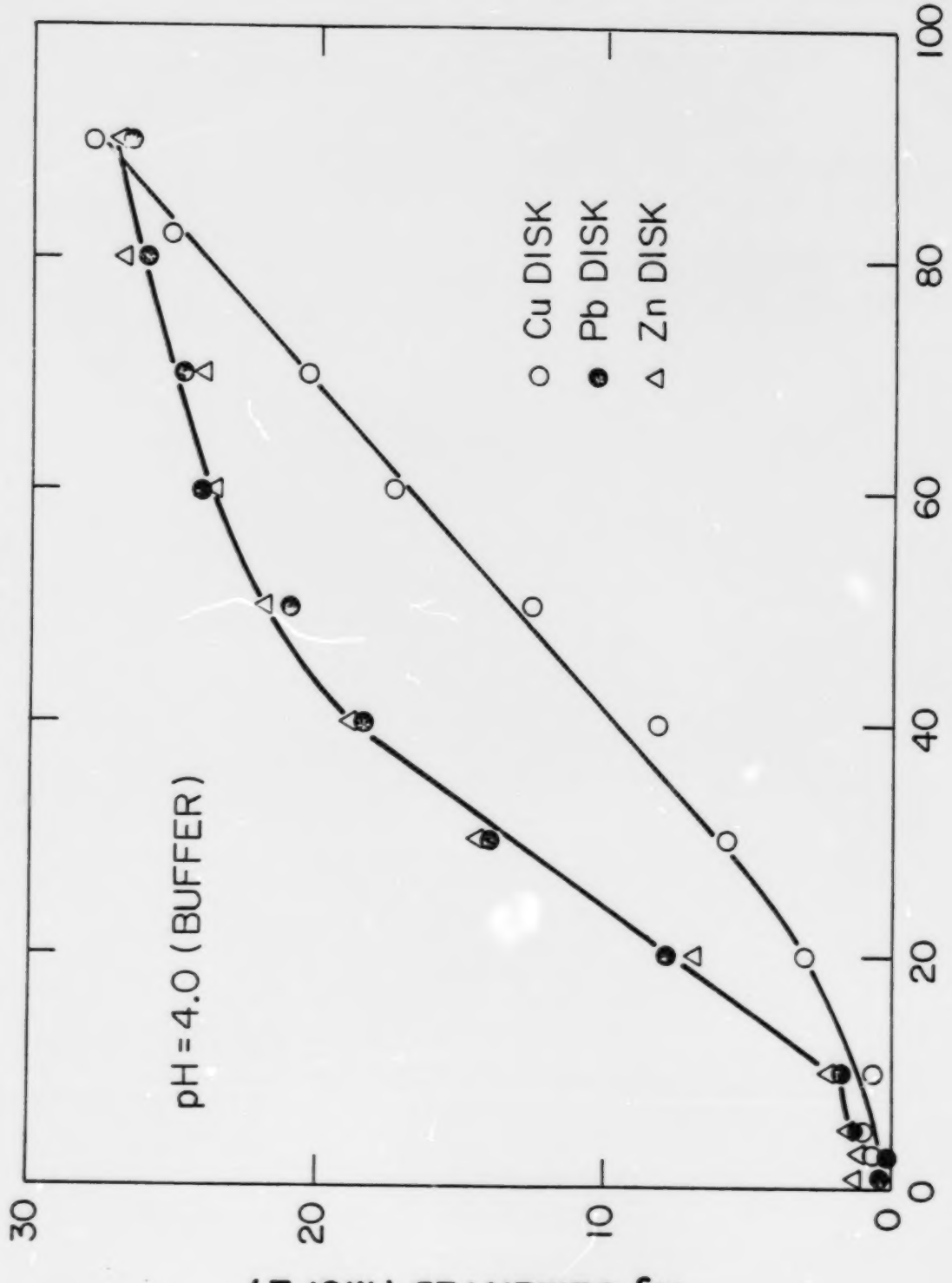
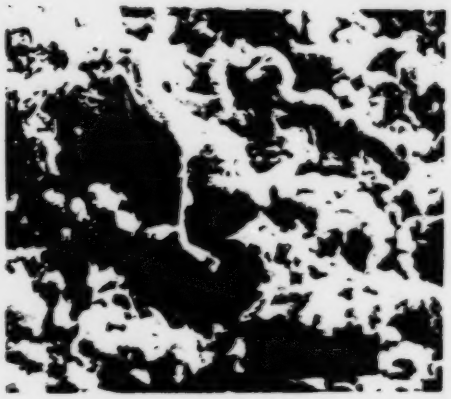

Ag CEMENTED (MG/L)
TIME (MIN)
pH = 4.0 (BUFFER)
Cu DISK
Pb DISK
Zn DISK
0
10
20
30
0
20
40
60
80
100

FIG. 5

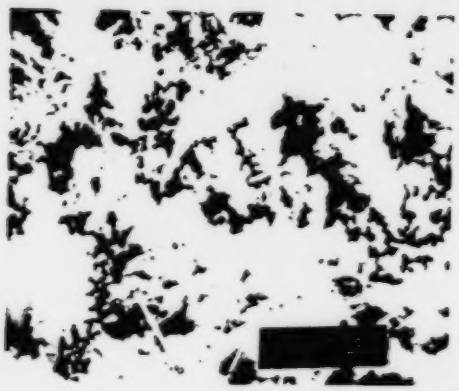
a) Cu Disk; pH 6.2

b) Cu Disk; pH 4.0

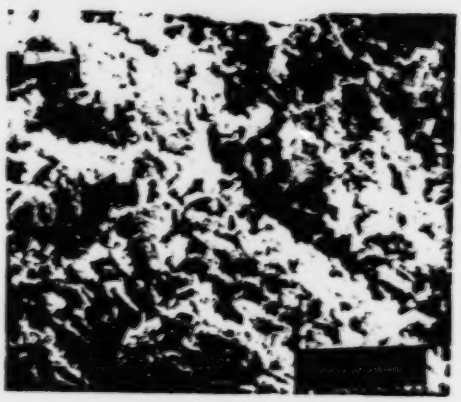
c) Pb Disk; pH 6.2



d) Pb Disk; pH 4.0



e) Zn Disk; pH 6.2



f) Zn Disk; pH 4.0

Figure 6 - SEM photomicrographs showing the effect of pH on the morphology of Ag cemented on Cu, Pb and Zn disks rotated at 1250 RPM in 3.0 M NaCl solution at 70°C.

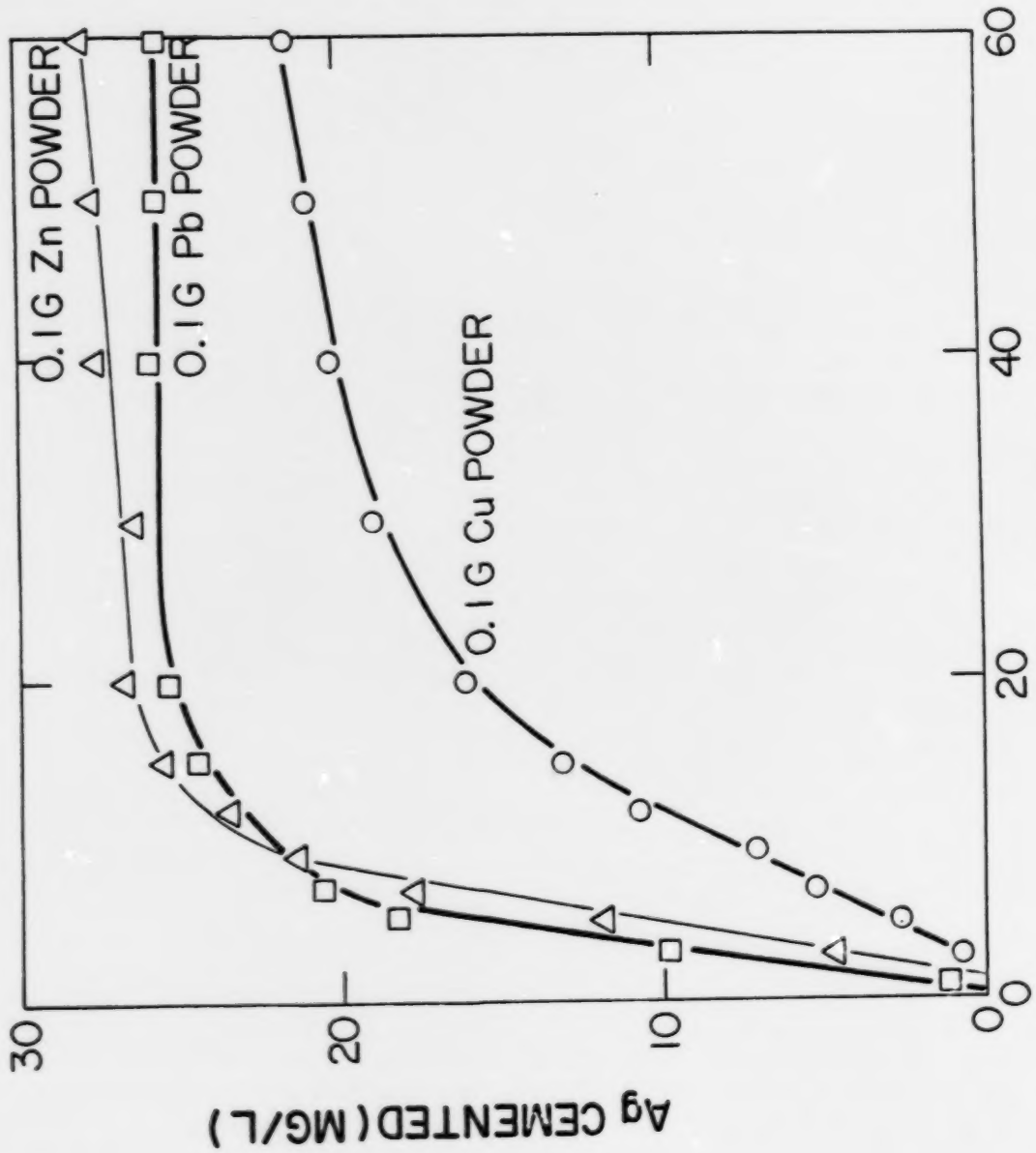
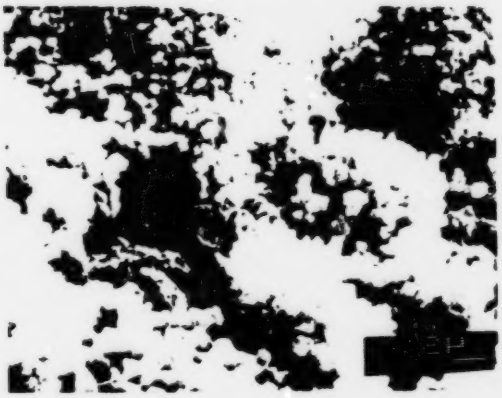
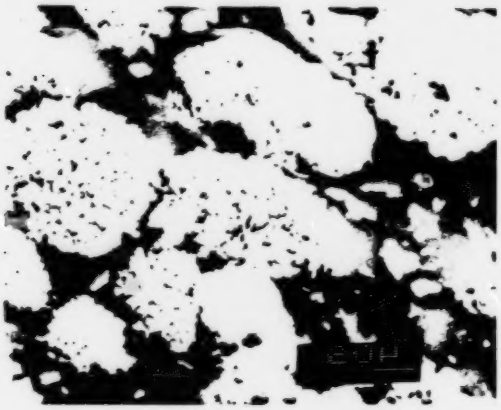

0.1G Zn POWDER
0.1G Pb POWDER
0.1G Cu POWDER
Ag CEMENTED (MG/L)
TIME (MIN)
0
10
20
30
0
20
40
60

FIG. 7



a) Cu Powder; pH 4.0



b) Pb Powder; pH 4.0

c) Zn Powder; pH 4.0

Figure 8 - SEM photomicrographs showing the morphology of Ag cemented on metal powders from a 3.0 M NaCl solution stirred at 1250 RPM at 70°C.

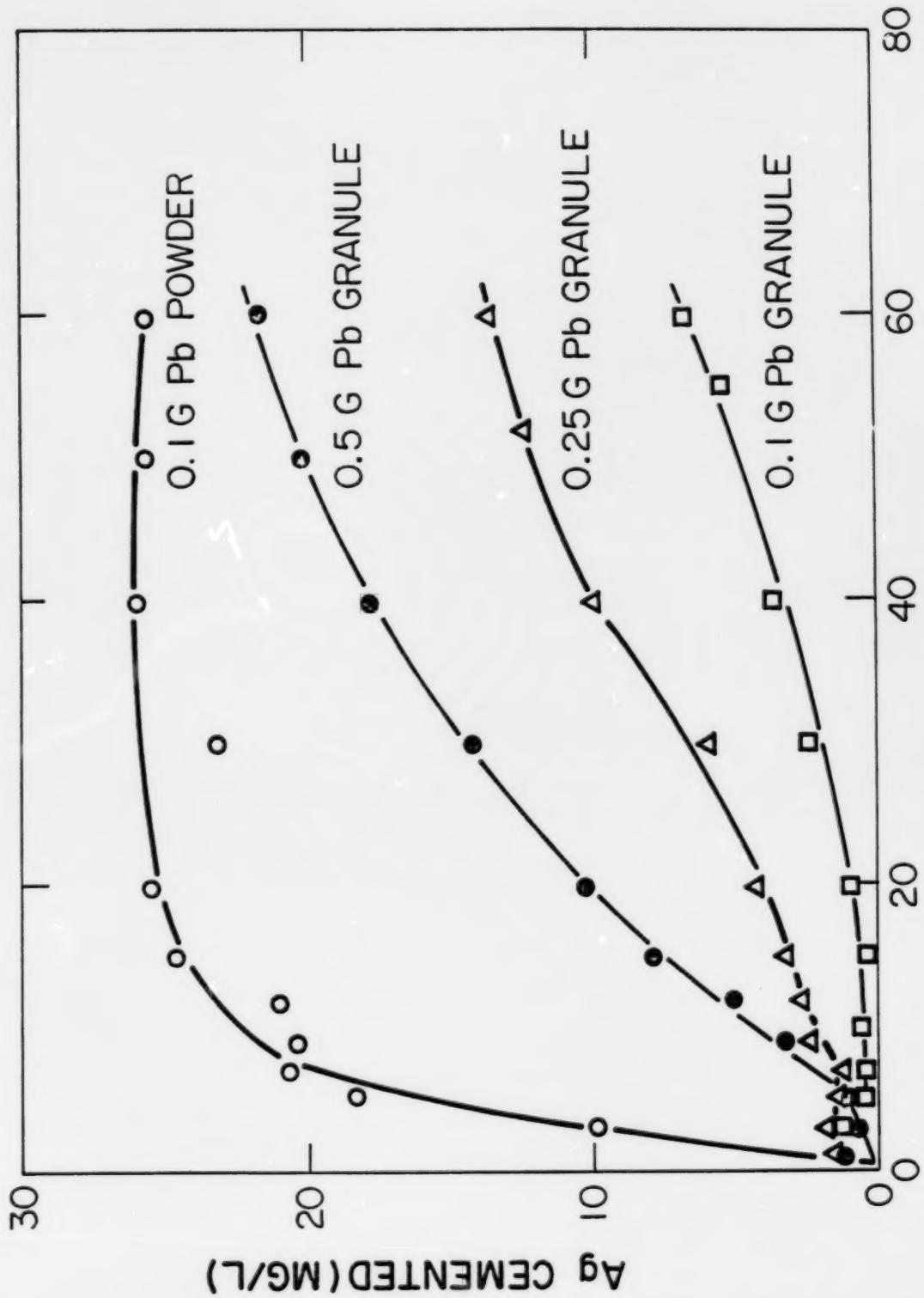

Ag CEMENTED (MG/L)
TIME (MIN)
0.1 G Pb POWDER
0.5 G Pb GRANULE
0.25 G Pb GRANULE
0.1 G Pb GRANULE
0
10
20
30
40
60
80

FIG. 9

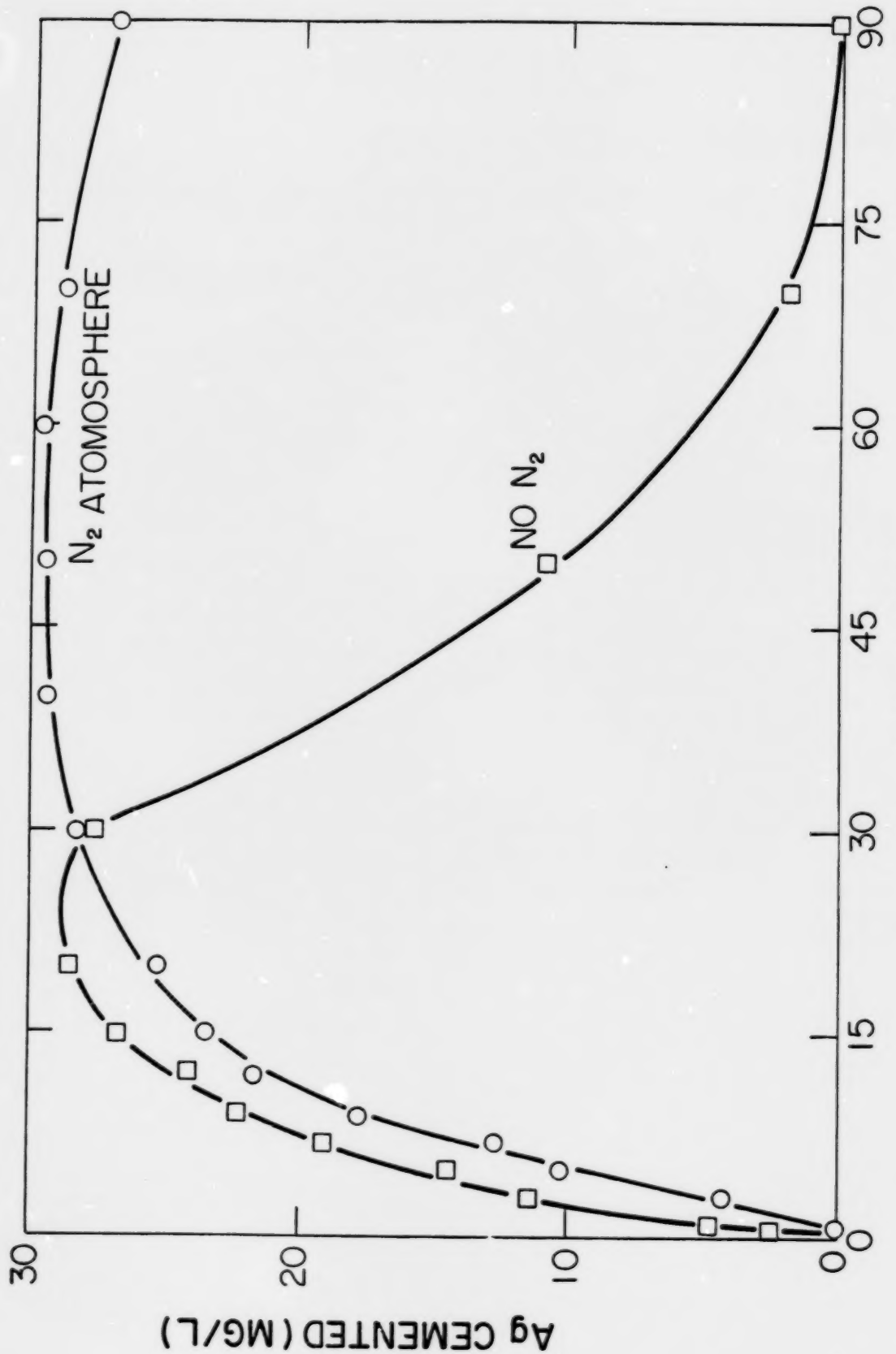

Ag CEMENTED (MG/L)
0
10
20
30
TIME (MIN)
0
15
30
45
60
75
90
N2 ATOMOSPHERE
NO N2

FIG. 10

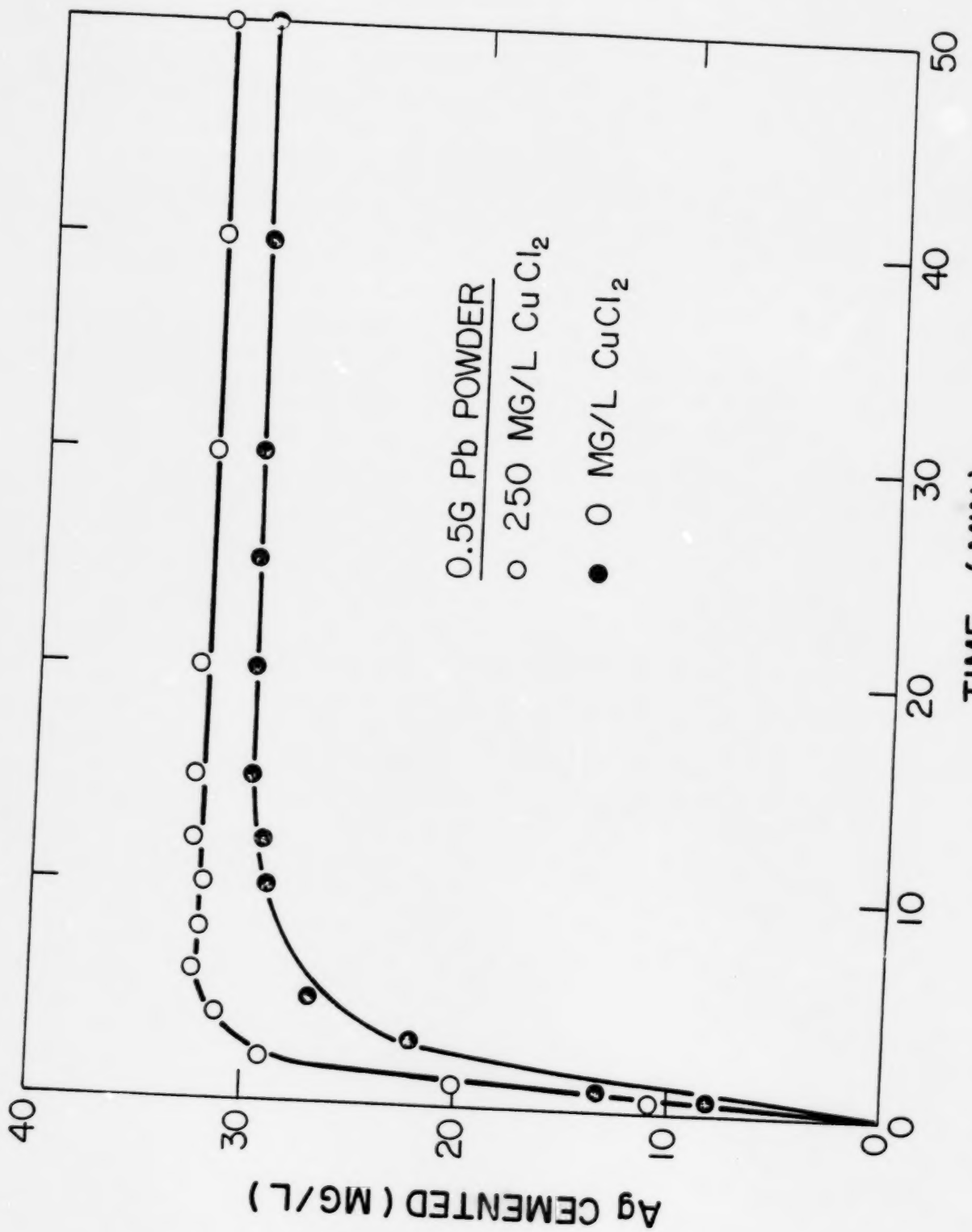

0.5G Pb POWDER
o 250 MG/L $CuCl_2$
● 0 MG/L $CuCl_2$
Ag CEMENTED (MG/L)
TIME (MIN)
0
10
20
30
40
50

FIG. 11

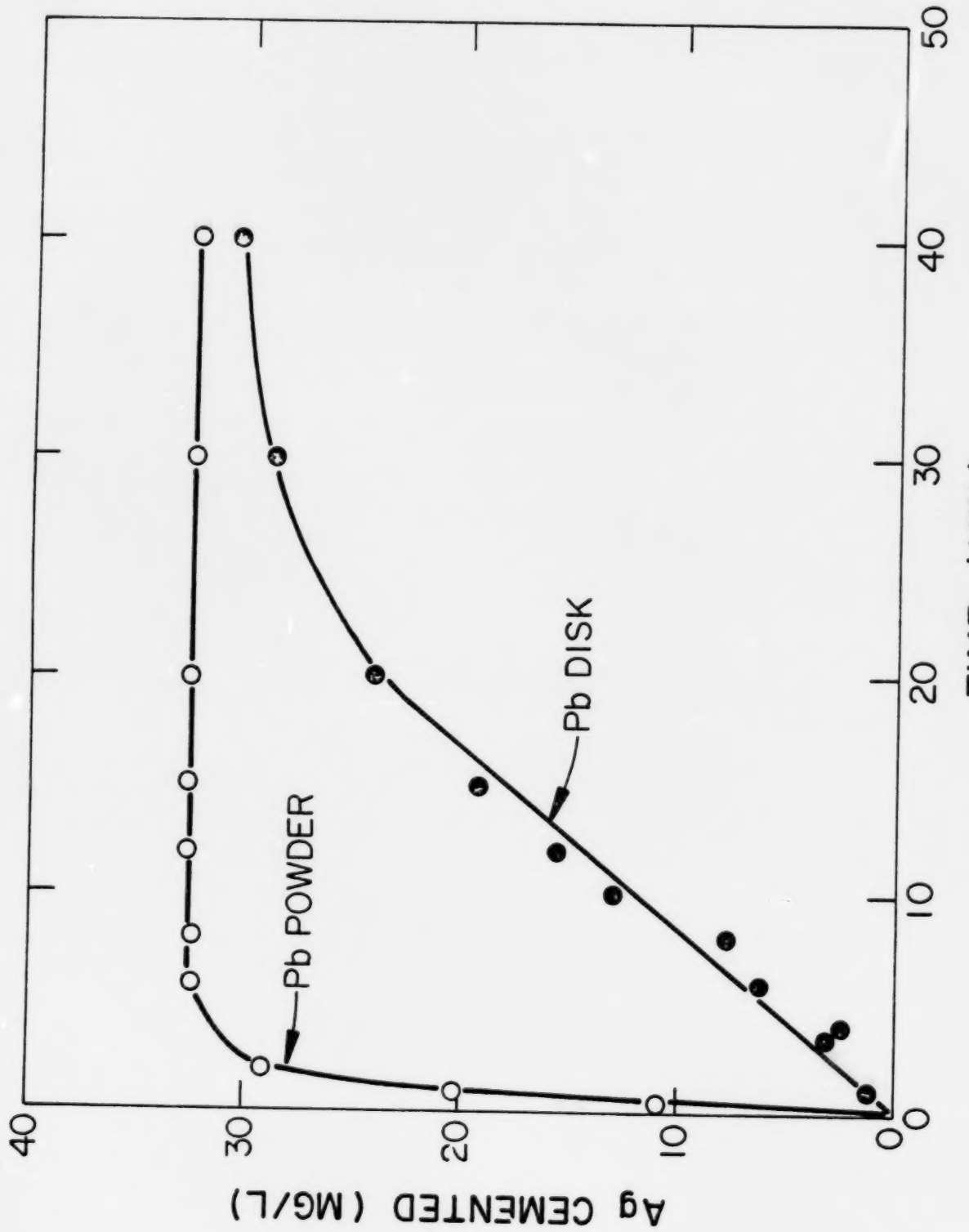



FIG. 12

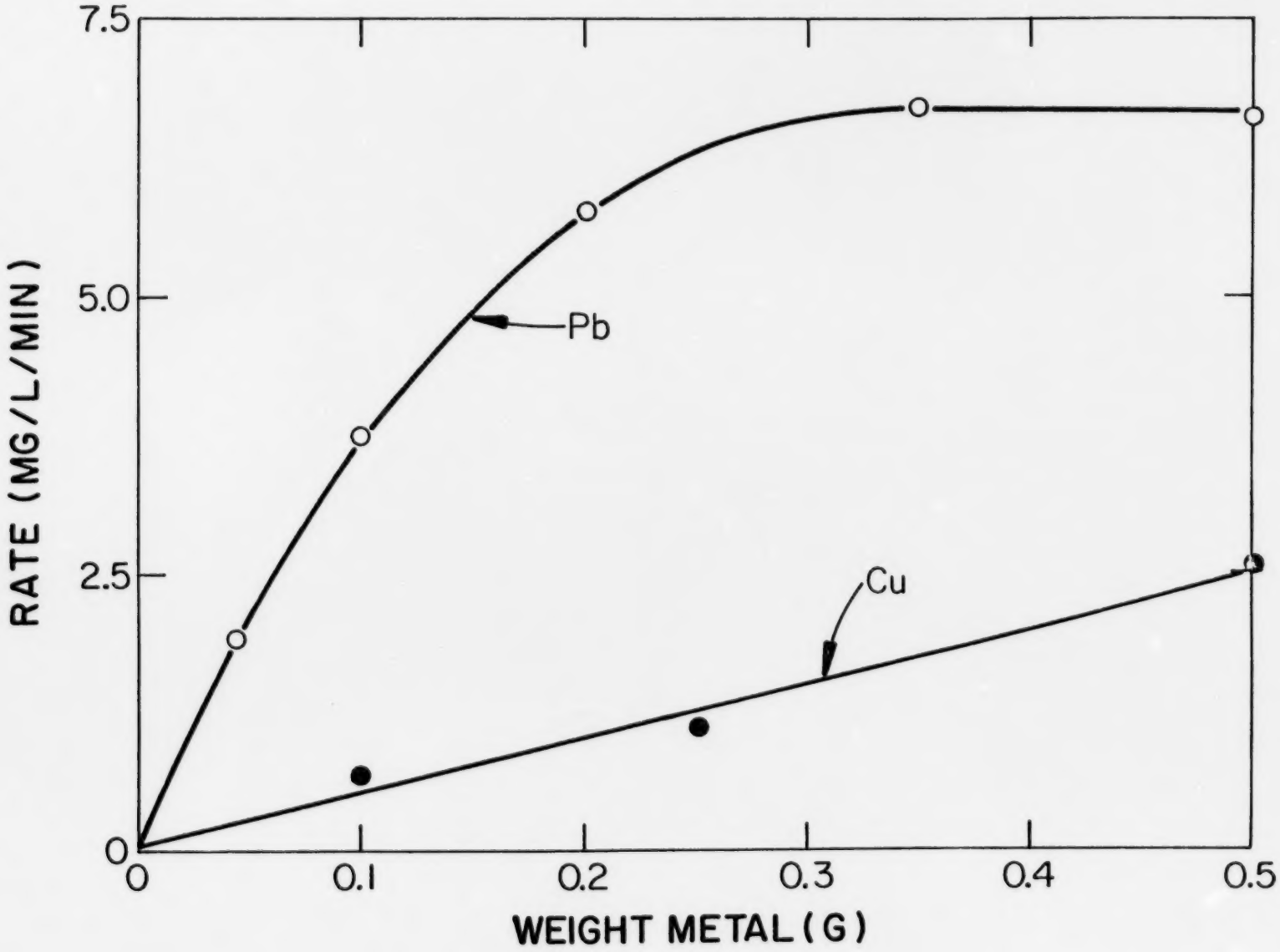



FIG. 13

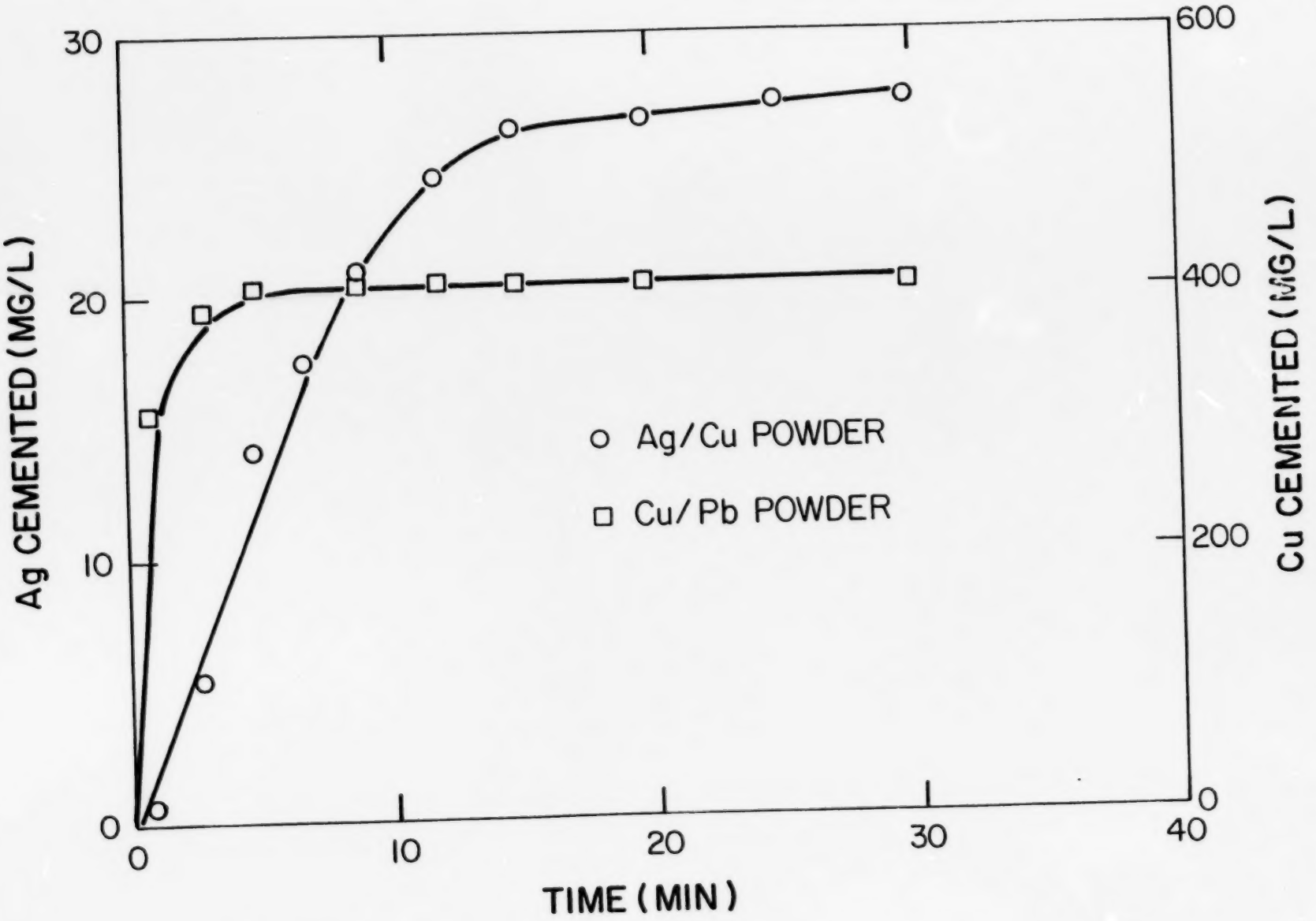

30
20
10
0
0
10
20
30
40
600
400
200
0
Ag CEMENTED (MG/L)
Cu CEMENTED (MG/L)
TIME (MIN)
Ag/Cu POWDER
Cu/Pb POWDER

FIG. 14

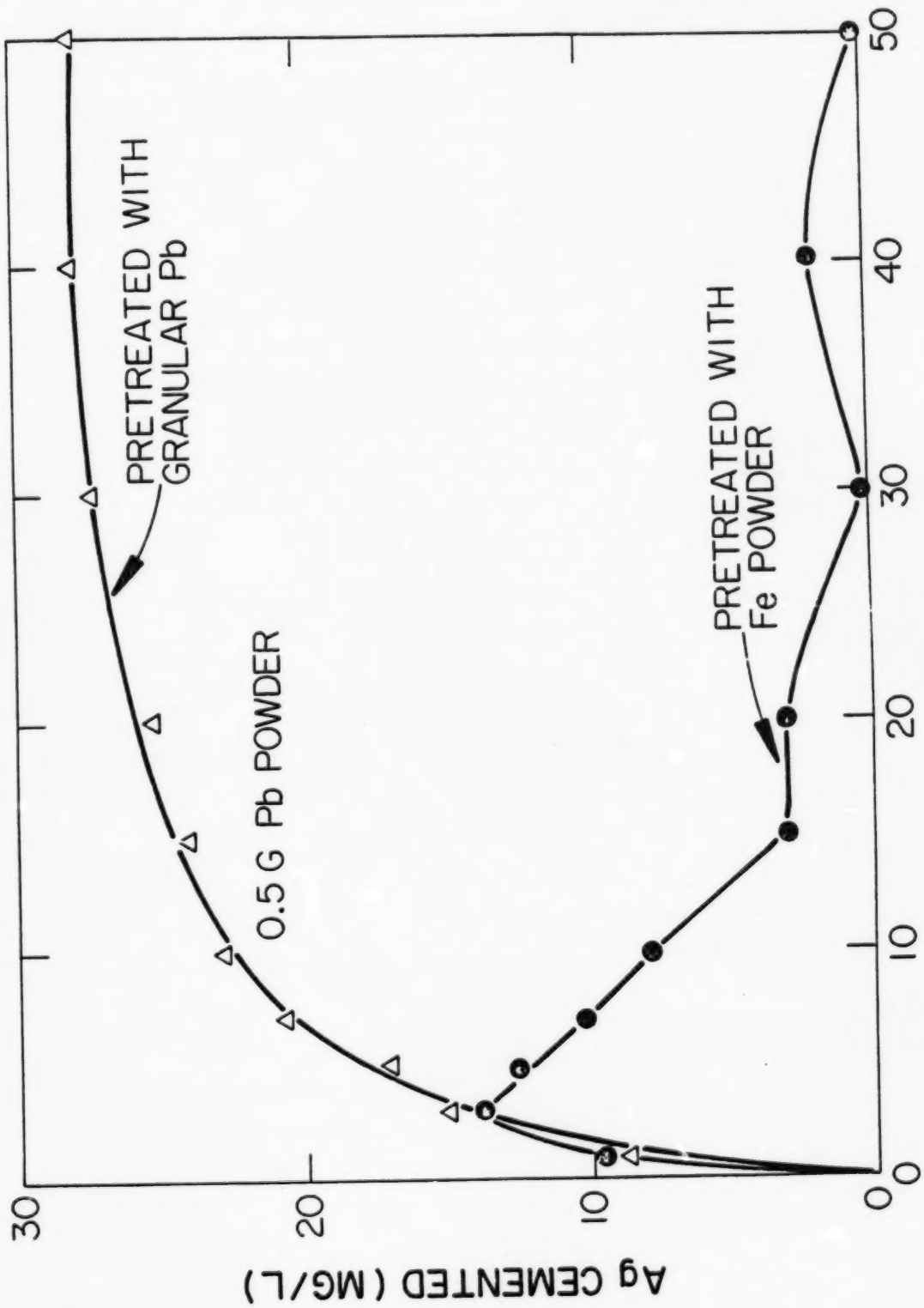

PRETREATED WITH
GRANULAR Pb
0.5 G Pb POWDER
PRETREATED WITH
Fe POWDER
Ag CEMENTED (MG/L)
TIME (MIN)
0
10
20
30
40
50

FIG. 15

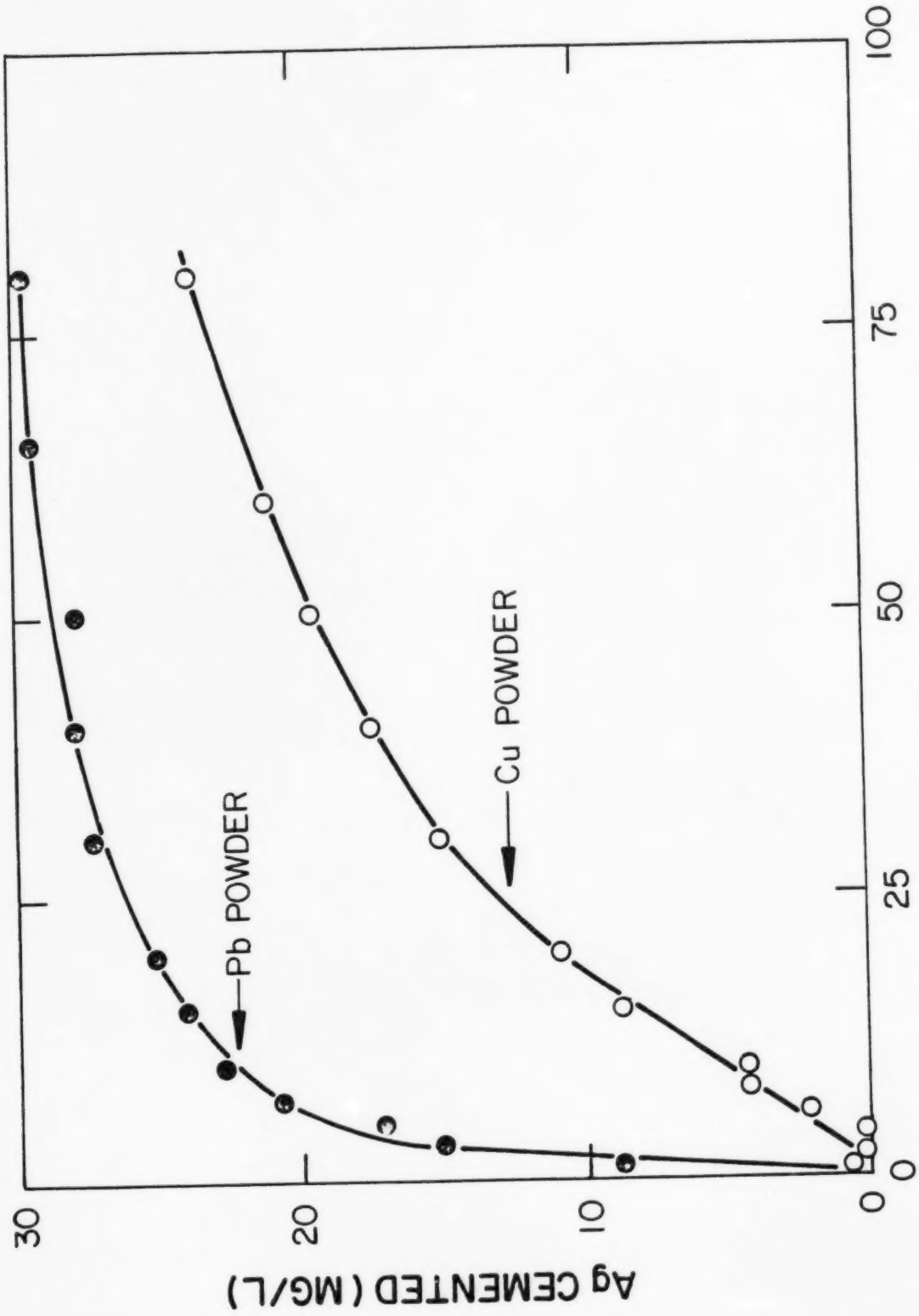

Ag CEMENTED (MG/L)
TIME (MIN)
Pb POWDER
Cu POWDER
0
10
20
30
0
25
50
75
100

FIG. 16

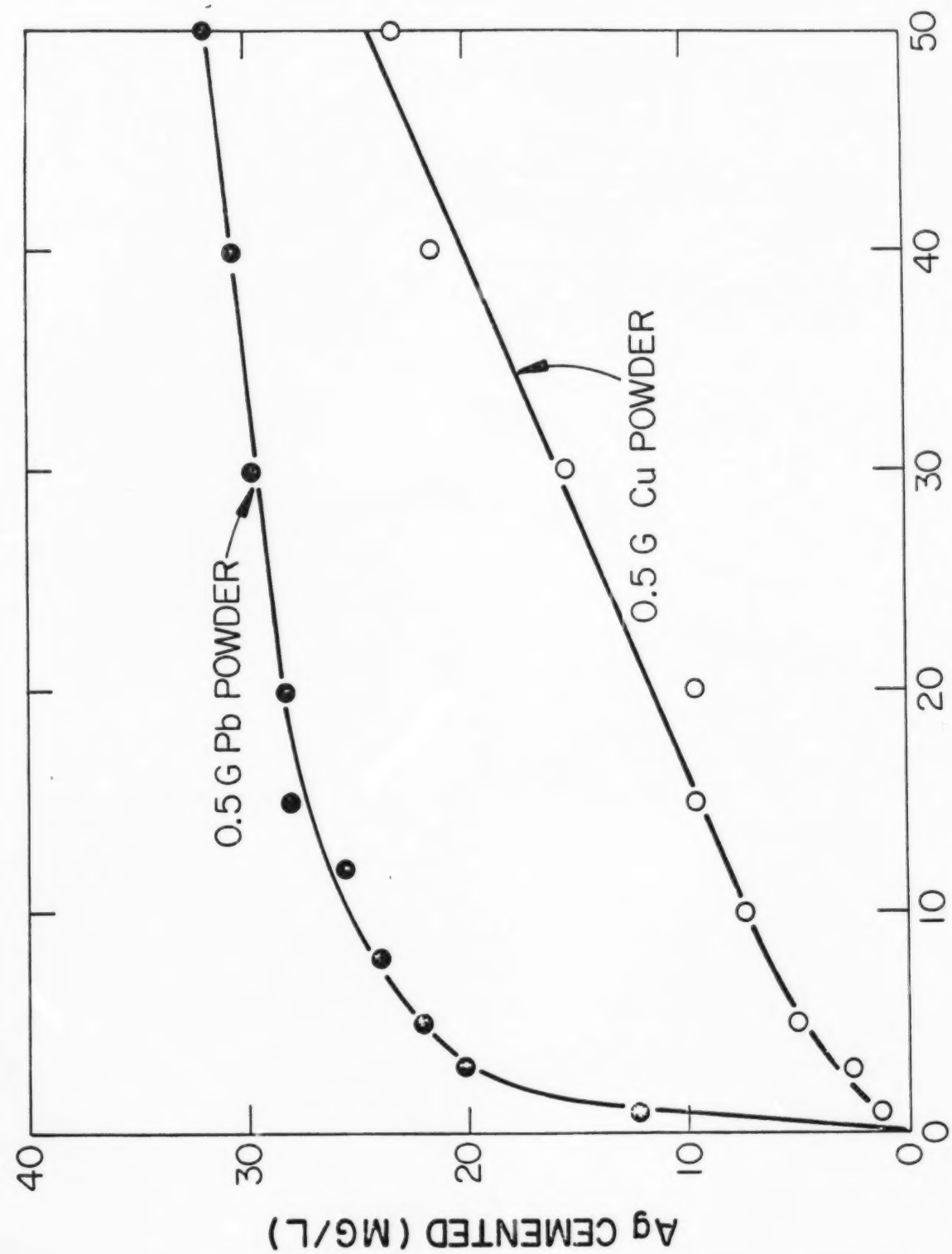

Ag CEMENTED (MG/L)
TIME (MIN)
0.5 G Pb POWDER
0.5 G Cu POWDER
0
10
20
30
40
50

FIG. 17